396360

65081

APRIL

1965

CONFIDENTIAL

ROYAL AIRCRAFT ESTABLISHMENT

TECHNICAL REPORT No. 65081

C

SIDE-EFFECTS OF FM BY HIGH FREQUENCIES ON M-TYPE BACKWARD WAVE OSCILLATOR VALVES (C)

by

A. Sewards, B.Sc.(Eng.), A.M.I.E.E.

W. F. J. Yeates, A.M.I.E.E.

MINISTRY OF AVIATION
FARNBOROUGH HANTS

CONFIDENTIAL

ACCESSION for		
CFSTI	WHITE SECTION	
DDC	BUFF SECTION	
UNANNOUNCED		✓
JUSTIFICATION		
BY		

DISTRIBUTION/AVAILABILITY CODES (FIELD 33)		
DIST.	AVAIL. and/or SPECIAL	
/3		

MINISTRY OF AVIATION

U.D.C. No. 621.385.633.24 : 621.376.3

ROYAL AIRCRAFT ESTABLISHMENT

(9) Technical Report [redacted]

(11) Apr[redacted] [redacted]65, (12) 38p.

(7) ~~SIDE EFFECTS OF FM BY HIGH FREQUENCIES ON~~
~~M-TYPE BACKWARD WAVE OSCILLATOR VALVES~~ (C). (8)

by

(10) A. Sewards[redacted] (Eng.) A.M.I.E.E.
W. F. J. Yeates, A.M.I.E.E.

(14) TR-65081

SUMMARY

The effect on six types of backward wave oscillator valve covering the frequency range from 520 to 1370 Mc/s and 2500 to 4000 Mc/s is described under conditions where they are frequency modulated at frequencies from 2.5 to 16 Mc/s over deviations extending to the full tuning range of the valve. The main effect common to all types is a reduction in RF power output, the greatest reduction occurring with high modulating frequencies and large deviations. It is concluded that if modulation over the tuning range of the valve is necessary, the highest usable modulating frequency ranges from 8 Mc/s for the lowest frequency valve tested to 16 Mc/s for the highest.

Departmental Reference: RAD.892

CONTENTS

1 INTRODUCTION

1.1 The backward wave oscillator valve (b.w.o.) or carcinotron is a voltage tunable microwave oscillator capable of being tuned at high rates over frequency ranges up to 25% of the centre frequency. Two broad classes of these valves are in current use; 'O-type', usually restricted to low power outputs (less than 1 watt), and 'M-type', normally producing in excess of 100 watts. In certain applications it is necessary to frequency modulate M-type b.w.o. valves over deviations comparable with the tuning range of the valve at frequencies extending from 1-20 Mc/s. Under such conditions the rate of change of frequency may become so large that the normal operating conditions of the valve are disturbed and the output power falls. Early work showed that quite serious loss of output power could result from frequency modulation with high frequency sine waves and a programme of experimental work was conducted to try and establish the relevant parameters and performance limitations of the various valves of interest.

1.2 The range of valves used in the tests were high power CW backward wave oscillators operating at line voltages in the 2-5 kV region at line currents of 350 mA, and covered the frequency range 520-1370 Mc/s and 2500-4000 Mc/s with power outputs of several hundred watts. Details are given in Appendix A. The work was conducted at two commercial laboratories as well as at R.A.E. Farnborough, and the valves were modulated at frequencies of 2.5, 5, 8, 10 and 16 Mc/s over deviations extending up to the tuning range of the valve concerned and the power outputs measured. The results showed that the lower frequency valves were most seriously affected, the maximum usable modulating frequency being in the region of 8 Mc/s, whilst the S-band valves could be modulated satisfactorily at 16 Mc/s. The important parameter was generally found to be the mean rate of change of frequency, or the product of total deviation and modulating frequency.

1.3 During the tests two other effects appeared and were investigated; namely the heating of the DC input connector of the two S-band and the C-band valve types due to dielectric losses associated with the modulating frequency, and resonance of the internal leads and electrodes of these S-band b.w.o. types. It was found that considerable, although not prohibitive, losses occurred with modulating frequencies in the region of 16 Mc/s when full deviation was employed, and deterioration of the connector socket was likely if this condition were prolonged. The electrode resonance effect was found to be not important for modulation frequencies less than about 20 Mc/s. It was also intended to conduct measurements on two Stage A samples of a C-band b.w.o. (VX3536) covering

the frequency range 5.1-6.7 Gc/s but it was found that the application of the 16 Mc/s modulation caused excessive heating and burning of the DC input socket.

1.4 The work described in this report commenced in 1961 and has been continued as further valves have been developed. Writing of the report has been delayed until all the results were available so that useful conclusions could be drawn.

2 EXPERIMENTAL EQUIPMENT

2.1 The work described in this report was conducted at three different laboratories, the Development Laboratory of the Compagnie generale de telegraphie sans fil (CSF) in Paris, the Research Laboratories of Plessey (UK) Ltd. Roke Manor, Romsey and Radio Department R.A.E. Farnborough. Three separate sets of equipment were thus employed of considerably different characteristics. However, as the basic methods were the same in all cases, a description of the equipment employed in the R.A.E. measurements will be included as an example.

2.2 The equipment used is shown in block diagram form in Fig.1 and consists essentially of an oscillator capable of producing sufficient output voltage to frequency modulate the backward wave oscillator under test over its entire tuning range. Two oscillators were constructed, each capable of producing 1000 V RMS across a load capacitance of 100 pF, operating at frequencies of 8 and 15/16 Mc/s. The output voltage was capable of being reduced by a factor of up to 20. A circuit diagram of the 15/16 Mc/s oscillator is shown in Fig.2, the 8 Mc/s version differing only in the values of the tuning and coupling inductors. The modulating voltage was applied to the cathode of the b.w.o. though a high voltage capacitor, the other electrodes of the b.w.o. with the exception of the line being decoupled to the cathode. The modulation thus appeared between the line and sole electrodes, frequency modulating the tube. Considerable care had to be taken to prevent the modulation signal passing into the regulated dc power supplies for the various b.w.o. electrodes, this being achieved by chokes and capacitors on each electrode lead close to the tube, with a substantial copper braid lead connecting the capacitors to ground. The connections are shown in Fig.3.

2.3 The RF output from the b.w.o. was fed, via a directional coupler, into a power measuring device consisting either of a water calorimeter or a second directional coupler plus thermistor bridge, depending on the frequency range of the tube under test. The signal from the first coupler was taken to a spectrum analyser to enable measurements of the degree of modulation to be made. Wideband spectrum analysers were used in all R.A.E. and Plessey measurements, the analysers employing either b.w.o.s or voltage tunable

magnetrons as local oscillators, thus enabling the entire modulation spectrum to be observed.

2.4 In order to obtain a reference power output for each b.w.o., provision was made to frequency modulate the tube up to its complete tuning range by means of a 50 c/s sinusoid. Under this condition the deviations were measured by means of a cavity wavemeter and detector.

3 EXPERIMENTAL PROCEDURE

3.1 As mentioned in 2.1 the results contained in this report have been obtained from measurements at three laboratories. Measurements at R.A.E. and Plessey were done with modulation frequencies of 8 and 15 or 16 Mc/s, whilst those done at C.S.F. used frequencies of 2.5, 5 and 10 Mc/s. The experimental procedure was, however, the same in all cases.

3.2 The selected b.w.o. was connected into the test circuit and allowed to run for a period to stabilise the frequency. The line voltage was adjusted so that the frequency of operation was in the centre of the tuning band and the line current set to the normal operating value (generally 350 mA for all tubes). When thermal stability was reached the 50 c/s modulation was applied and increased to give modulation over the complete range, the power output then being recorded. The 50 c/s modulation was then removed and replaced by the appropriate frequency being used of 8 or 16 Mc/s. The RF power output was then recorded for various values of deviation up to the maximum tuning range of the tube. As a check, measurements were also made of the modulator output voltage for each deviation increment.

3.3 The method adopted for the measurement of deviation is of interest and will be described in more detail. Generally speaking, it is difficult to decide accurately from observation on a spectrum analyser what the frequency limits of a frequency modulated spectrum are, particularly if a high frequency modulating waveform is in use. No attempt was made to use the spectrum analyser in this way in these measurements but instead the amplitude of the carrier or first or second sidebands was closely observed and the modulation voltage adjusted so that minima of the appropriate sidebands were produced. (If no amplitude modulation were present, these minima would be true zeros. However, because the power output varies with frequency some amplitude modulation inevitably occurs.) With a knowledge of the modulation frequency the deviation could readily be calculated from tables of zeros of Bessel functions. The method is described more fully in Appendix B and has been found to produce accurate, repeatable results.

4 RESULTS

4.1 Results have been produced in the form of graphs illustrating the variation of b.w.o. RF output power with deviation for the various modulation frequencies for each tube tested. Considerable differences existed between different tubes of the same type and also, as expected, between different tube types. Table 1 summarises the measurements made on the various tubes, the modulation frequencies used, and the appropriate graphs illustrating the results for each tube type.

Table 1

SUMMARY OF TESTS MADE

Tube type	Frequency range Mc/s	No. tested	Modulation frequency Mc/s	Figure
VX9224 (CV6102)	520-670	6	5, 8, 10	4, 5
VX9239 (CV6124)	660-860	6	2.5, 5, 8, 10, 16	6, 7, 8
VX9250	850-1100	8	2.5, 5, 10	9, 10
VX9240	1060-1370	4	2.5, 5, 10	11, 12
VX3510 (CV2470)	2500-3100	3	16	13
VX3512 (CV2471)	3000-4000	4	16	14
VX3536	5100-6700	2	16 Severe burning of dc input socket prevented test continuing.	

4.2 In order to illustrate the trends when modulating b.w.o.s at high frequencies a second series of graphs have been produced in which the power output is plotted as a function of the product (total deviation × modulating frequency), i.e., $(2\Delta F \cdot f)$. In these graphs the results for the various modulating frequencies tend to fall on the same curve, thus indicating that the parameter determining the power loss is this product and not simply the deviation or the modulating frequency.

4.3 Detailed results for valve types

4.3.1 VX9224/CV6102

Fig.4 illustrates the fall off in power output as the modulating frequency and deviation are increased. At 5 Mc/s little fall off occurs even at deviations equal to the tuning range of the valve. At 8 Mc/s the power is approximately halved with 100 Mc/s deviation whilst 10 Mc/s causes a fall to less than 100 W (-6 dB) when deviations in excess of 100 Mc/s are employed. Fig.5 summarises this in the plot of the product $(2\Delta F \cdot f)$ against power output. The safe maximum value for the valves tested lies in the region of 800 (Mc/s $\times$ Mc/s). It is interesting to note from Fig.5 that two distinct families of curves appear although all the valves are of nominally identical construction.

4.3.2 VX9239/CV6124

As in the VX9224 the fall off in power illustrated in Fig.6 increases with increasing modulating frequency and deviation. 2.5 and 5 Mc/s cause little loss of power even at full deviation but at 8 Mc/s the power output is rather more than halved under this condition. The 10 Mc/s figures vary rather more from valve to valve and serious losses of power result for some valves (-8 dB). The loss of power when a modulating frequency of 16 Mc/s was used was very rapid for increases in deviation above a few tens of Mc/s. The plotting of curves relating power output to $(2\Delta F \cdot f)$ was found to be difficult as the power losses for given $(2\Delta F \cdot f)$ products for different modulation frequencies varied considerably - see Fig.7. Fig.8 therefore is plotted with the points obtained from all the tests made but not joined up for particular valves. The same general shape as in Fig.5 is seen to emerge, the limiting product being around 1000.

4.3.3 VX9250

With this valve type extremely consistent results were obtained from the eight valves tested, so much so that it was not possible to separate the lines of several of them. As before the same general shapes are illustrated in Fig.9 but for this valve type a modulating frequency of 10 Mc/s only causes little over a halving of output power at full deviation. Fig.10 illustrates the $(2\Delta F \cdot f)$ vs. power characteristic and it appears that the limiting product is about 1500.

4.3.4 VX9240

Results for the VX9240 valves tested are similar to those of VX9250 in that modulation at 10 Mc/s over the full deviation causes a power fall of

about half (Fig. 11). Because of the wider tuning range the limiting value of the product thus increases to about 2000 (Fig. 12). There was, however, a considerable scatter in the results for the few valves tested, one in particular being considerably different. It is possible that, as in the case of the VX9224, two distinct families of curves exist but insufficient valves were tested to arrive at any definite conclusion.

4.3.5 VX3510/CV2470

These valves were only tested at 16 Mc/s modulating frequency and so the graphs of power vs. deviation and product ($2\Delta F \cdot f$) are combined. It is difficult to arrive at any useful conclusions on the results of the three valves tested as three distinctly different characteristics resulted - Fig. 13. Both the higher powered valves showed a tendency to lose power as the deviation was increased but the low power valve actually gave more power at full deviation. The limiting valve of ($2\Delta F \cdot f$) assumed for this valve is therefore rather arbitrarily chosen at 10000.

4.3.6 VX3512/CV2471

The results for this tube type were much more in line with the others than the VX3510, and showed the general tendency of loss of power with increasing deviation - see Fig. 14. The limiting product is taken as 15000. It seems likely that both this valve type and the VX3510 can be modulated over their tuning ranges at 16 Mc/s without serious loss of power but tests on more valves are really required to be certain.

4.3.7 VX3536

As mentioned in Section 1 tests on two samples of this valve were attempted with a modulating frequency of 16 Mc/s. When more than a few tens of volts of modulation were applied, burning of the material in the dc input socket occurred and it was not possible to make any useful measurements.

4.4 In the course of performing the tests on the S-band b.w.o.s, VX3510/CV2470 and VX3512/CV2471, it was noticed that the Q factor of the resonant circuit which included the b.w.o. capacitance was much lower than with the other tube types tested, and that when the tubes had been operated at large deviations for some time considerable heating of the dc input socket occurred. Further investigation revealed that the cause of these effects was the rubber material with which the dc input socket is filled, which exhibits considerable loss at frequencies of about 10 Mc/s and above. Measurements with a Q-meter on the line-sole electrode connections of a cold b.w.o. indicated an equivalent shunt loss resistance in the region of 13 kΩ at

16 Mc/s, which would dissipate some 40 watts with sufficient 16 Mc/s modulating voltage to fully deviate the valve.

4.5 Measurements of input impedance at frequencies in the 10-30 Mc/s region of VX3510/CV2470 and VX3512/CV2471 valves were made in the course of the investigation mentioned in 4.4 above. These showed that at frequencies within this band resonances occurred of the b.w.o. internal electrodes with the leads from the dc input socket (Fig.15). Under conditions of series resonance of the sole-line capacitance with the sole lead inductance it is possible to have an appreciably larger modulation voltage appearing across between line and sole than is applied at the input socket of the valve. However, these effects occur mainly in the region of 30 Mc/s, which is too high for useful modulation purposes, and vary considerably from valve to valve.

5 DISCUSSION OF RESULTS

5.1 The general form of the graphs illustrating the effect on a particular b.w.o. type is a decrease in power output with increasing deviation, the reduction being greater the higher the modulating frequency. The graphs showing the variation of power with $(2\Delta F \cdot f)$ do in general illustrate that the power reduction is proportional to this quantity rather than just the deviation or modulating frequency. The quantity $(2\Delta F \cdot f)$ is equal to the mean rate of change of frequency and thus it is not surprising that it is an important parameter.

5.2 Appendix C contains a brief derivation associating the mean rate of change of frequency under modulation conditions $(2\Delta F \cdot f)$ with other parameters of the valve such as the oscillation build-up time and the transit time along the delay line. From this it is shown that $[(2\Delta F \cdot f)\ t/f_{mid}]$ should be constant for all valves (of similar design and operating conditions). The various values of this expression have been calculated for the tube types tested from the measured results and known tube parameters and are given in Table 2. It can be seen that the values vary from 23 to 35 $\times 10^{-3}$. Such a variation is small for the wide frequency range covered by the valves (520 Mc/s to 4000 Mc/s) and tends to confirm the argument advanced in Appendix C.

5.3 As the valves in the experiments described in this report were modulated by sinusoidal waveforms, the expression $(2\Delta F \cdot f)$ is only the mean rate of change, as if the waveform were triangular. The actual rates vary over the cycle from zero to rather faster than the mean. There will thus be a tendency for the loss of power to vary over the modulation cycle, being greatest near the zero crossings and least at the extremities. This indicates a greater

loss of power in the sidebands near the carrier as compared with those at the extremities of the deviation. It was not possible in the experiments described to observe this effect because of the variable sensitivity of the spectrum analysers as a function of frequency.

5.4 There is some evidence, notably in Fig.5, for a particular valve type to have two distinct families of curves although the valves are of nominally identical construction. The two sets are those which exhibit a rapid fall off in power, followed by a tendency to flatten out at around 100 watts, and those which maintain high power out to roughly twice the deviation and then exhibit a rapid fall off. On the limited number tested there was a tendency for the valves with high initial powers to be of the first type, while those of lower normal output were of the second. A possible explanation, if this is the case, is that the high power valves have a more efficient interaction between the RF wave and the electron beam, and are thus proportionally more disturbed by the modulation. However, in view of the paucity of data this can be regarded as no more than a suggestion. A similar effect is also exhibited by VX3510/CV2470 (Fig.13) where the higher power valves are more affected by the 16 Mc/s modulation.

5.5 As shown in Figs.6, 7 and 8, it was not possible to draw useful curves relating ($2\Delta F \cdot f$) to the output power for the VX9239/CV6124 valves tested, as the values of power for the same ($2\Delta F \cdot f$) for different modulating frequencies differed widely (Fig.7). Fig.8 therefore is made up of all the points measured and calculated as ($2\Delta F \cdot f$) to give an impression of the shape. From this has been derived the value of ($2\Delta F \cdot f$) at -3 dB power used in Table 2. The reason for the variability of the effects on this valve type are not understood.

5.6 Difficulties were experienced during the tests on the S and C-band valves due to the presence of lossy material in the dc input socket and long connecting leads in the valve. These difficulties are impossible to avoid once the valve has been manufactured and it should be standard practice to avoid such materials on any new designs of valve which may need to be modulated at high frequencies.

6 CONCLUSIONS

6.1 The effect on a backward wave oscillator tube of frequency modulation at a high frequency is to cause a reduction in output power. The reduction is greater for high frequencies and large deviations. Quite serious reductions can be exhibited by b.w.o.s, for example normal output powers in excess of 300 W falling to less than 50 W when modulated at 10 Mc/s in the case of VX9224.

6.2 For deviations comparable with the tuning range of the valve the effect of modulation at a particular frequency is less for valves operating at the higher frequencies. It is thus difficult to choose a single high modulating frequency suitable for modulating a range of b.w.o.s extending from say 500 Mc/s to 4000 Mc/s if substantial deviations are required. For full deviations the maximum modulation frequencies vary from about 8 Mc/s for the VX9224/CV6102 (520-670 Mc/s) to around 16 Mc/s for VX3512/CV2471 (3000-4000 Mc/s).

6.3 For the majority of valves tested the power loss appeared to be related to the product of the deviation and the modulating frequency (approximately the rate of change of frequency). Each valve type had a limiting value of this product beyond which substantial loss of power occurred. This value varied from about 800 for VX9224/CV6102 to something in the region of 15000 for VX3512/CV2471. With a knowledge of the limiting value it is possible to estimate the maximum modulating frequency that can be employed with a desired deviation.

6.4 The results of the experimental work described in the report tend to confirm the existence of a useful relation between the limiting product and certain valve design parameters. It should thus be possible, with a knowledge of the delay line length and dispersion ratio for a particular valve type, to predict the approximate limiting value of the product. This is, however, only likely to be true if the b.w.o. concerned has been designed on classical principles and employs similar electrode voltages and currents to those tested here.

6.5 The tests on the S-band b.w.o.s VX3510/CV2470 and VX3512/CV2471, and the C-band VX3536 showed that the types of dc input socket used introduced difficulties in modulating the valves at high frequencies over large deviations because of two separate effects. The more serious difficulty is the loss of modulation frequency power in the rubber material with which the plug is filled, which causes an increase in modulator power required and heating of the plug. The other effect is only likely to be important if frequencies in excess of 20 Mc/s are employed, and is the tendency for the sole to line capacitance of the tube to resonate with the series inductance of the relatively long input leads employed in the valve and input socket of the S-band valves. This latter effect may in some cases be beneficial as far as modulation power requirements are concerned but the effect varies from valve to valve. Care should be taken in new valve designs to avoid the use of such lossy materials and to keep electrode leads short.

ACKNOWLEDGMENTS

The results described in this report have been obtained from experiments conducted at the laboratories of Plessey (UK) Ltd. at Roke Manor, Romsey and the Compagnie generale de telegraphie sans fil, Paris, as well as at Radio Department, R.A.E. The assistance of all who contributed, in the construction of equipment and suggestions for measurement techniques as well as the actual experiments, is gratefully acknowledged.

Appendix A

DETAILS OF BACKWARD WAVE OSCILLATOR VALVE TYPES USED IN TESTS

Valve type	Frequency range Mc/s	Minimum power output watts	Typical power output watts	Line to rest capacitance pF	Line voltage range kV min.	max.
VX9224 CV6102	520-670	250	350	125	1.5	5.0
VX9239 CV6124	660-860	250	500	125		
VX9250	850-1100	250	450	105		
VX9240	1060-1370	200	450	105		
VX3510 CV2470	2500-3100	150	350	65	2.0	5.1
VX3512 CV2471	3000-4000	150	300	65		

ELECTRODE VOLTAGES AND CURRENTS
(all valves)

Line current (operating)	350 mA
Sole voltage (min - max)	-500 to -1500
Sole current (max)	-80 mA
Line voltage variation to tune valve over frequency range (max)	2.5 kV
Plate voltage (max)	2 kV

Appendix B

A METHOD OF MEASURING THE DEVIATION OF A CARRIER FREQUENCY MODULATED BY A SINUSOIDAL WAVEFORM

B.1 When a carrier is frequency modulated by a sinusoidal waveform, the resulting RF spectrum consists of a series of lines spaced by the modulating frequency extending approximately from one deviation extremity to the other. The amplitude of the lines is given by the expression

$$a = A \sin (2\pi F t + M \sin 2\pi f t) \qquad (1)$$

where F = carrier frequency
f = modulating frequency
M = modulation index = $\Delta F/f$
ΔF = deviation.

The expansion of expression (1) is the well known one involving Bessel coefficients, as follows:-

$$\begin{aligned} a = A \{ J_0(M) \sin 2\pi F t & \pm J_1(M) \sin 2\pi(F \pm f)t \\ & + J_2(M) \sin 2\pi(F \pm 2f)t \\ & \pm J_3(M) \sin 2\pi(F \pm 3f)t \\ & \text{etc.} \qquad \} . \end{aligned} \qquad (2)$$

From expression (2) it can be seen that the amplitudes of the various lines are given by the coefficient $J_n(M)$ for the pair of sidebands of order n from the carrier. For certain values of M it is clear that $J_0(M)$ will be zero and for this value of modulation index the carrier will disappear. For a fixed modulating frequency therefore, and a variable deviation the carrier will disappear at values of M such that $J_0(M) = 0$, i.e., M = 2.4, 5.52, 8.65 etc. Similarly, the pair of sidebands adjacent to the carrier will disappear when the modulation index is such that $J_1(M) = 0$, i.e., when M = 3.83, 7.01, 10.17 etc; and so on for all the other sidebands.

B.2 The deviation is therefore readily obtained by observing with a wavemeter tuned to the appropriate frequency or a spectrum analyser the amplitude of the appropriate sideband. Adjustment of the deviation will cause the amplitude to fall to zero and by reference to a table of zeros of Bessel functions and a knowledge of the modulating frequency the deviation can be quickly calculated.

In practice it is quite easy to observe the disappearance of the sideband and the method has been found to give accurate, repeatable results.

B.3 The sidebands and zeros used should be chosen in relation to the modulation index expected. For low indices the first few zeros of J_o and J_1 are quite sufficient and are easy to distinguish: these were generally used in the measurements on the low frequency b.w.o. valves. For large values of M it is more appropriate to employ the first zeros of the higher order functions J_{10}, J_{11} etc. The measurements made on the S-band valves, for example, employed the first zero of the odd numbered sidebands up to J_{27}, which corresponded to a peak to peak deviation of 1053 Mc/s for a modulating frequency of 16 Mc/s.

B.4 The above discussion assumes that pure frequency modulation of a carrier only is present. In the case of backward wave oscillators, the power output varies with frequency by typically 2 dB over the operating range of the valve, and thus frequency modulation causes incidental amplitude modulation. A curve showing the typical variation of power output with frequency is given in Fig.16. The effect of the incidental amplitude modulation is to prevent the amplitude of a particular line falling to zero and thus it is necessary to adjust the deviation to give a minimum rather than a zero. In practice, with the degree of amplitude modulation present, the minima observed on spectrum analysers approach zeros.

B.5 Because of this variation of output power with operating frequency the unmodulated power at the centre band frequency cannot be used as a reference. A mean output power for the operating range of the valve was obtained by modulating with a 50 c/s sine wave over the complete tuning range.

Appendix C

THE EFFECT OF FREQUENCY MODULATION ON A BACKWARD WAVE OSCILLATOR

Consider a bandwidth B within which interaction of the RF wave on the slow wave structure and the electron beam can occur successfully and oscillation build up take place. Then provided the rate of change of frequency is less than this bandwidth in the build up time of the oscillations it can be assumed that little or no loss of power will result from FM. We can say therefore that for negligible power loss

$$\frac{df}{dt} < \frac{B}{T} \qquad T = \text{build up time} \; .$$

Now $T = kt$ where $t =$ transit time of electrons along the slow wave structure. Therefore

$$\frac{df}{dt} < \frac{B}{kt} \; .$$

But B will be proportional to the tube centre frequency for a classical inter-digital line and thus

$$B = k' \cdot f_{mid} \; .$$

We therefore have the limiting condition beyond which power loss will occur:

$$\frac{df}{dt} = \frac{k' f_{mid}}{kt} = k'' \cdot \frac{f_{mid}}{t} \; .$$

Approximating df/dt to the mean rate of change of frequency $(2\Delta F \cdot f)$ we have

$$(2\Delta F \cdot f) = k'' \cdot \frac{f_{mid}}{t} \quad \text{or}$$

$$\frac{(2\Delta F \cdot f) \cdot t}{f_{mid}} = \text{constant } (k'') \; .$$

Table 2

PARAMETERS OF THE VALVE TYPES TESTED

Valve type	Frequency range Mc/s	Mid band frequency (f_{mid}) Mc/s	Limiting value of $(2\Delta F \cdot f)$ (half power)	Effective delay line length cm	Delay line velocity ratio c/v (mid band)	Transit time (t) sec	$\frac{(2\Delta F \cdot f) \cdot t}{f_{mid}}$
VX9224 CV6102	520-670	595	800×10^{12}	35	22	26×10^{-9}	35×10^{-3}
VX9239 CV6124	660-860	760	1000×10^{12}	30	19	19×10^{-9}	25×10^{-3}
VX9250	850-1100	975	1500×10^{12}	25	18.4	15×10^{-9}	23×10^{-3}
VX9240	1060-1370	1215	2000×10^{12}	26	19	16×10^{-9}	26×10^{-3}
VX3510 CV2470	2500-3100	2750	(?)* 10000×10^{12}	13	18.5	8×10^{-9}	28×10^{-3}
VX3512 CV2471	3000-4000	3500	(?)* 15000×10^{12}	11	17	6×10^{-9}	26×10^{-3}

*Estimated values, half power point not reached and number of valves tested small.

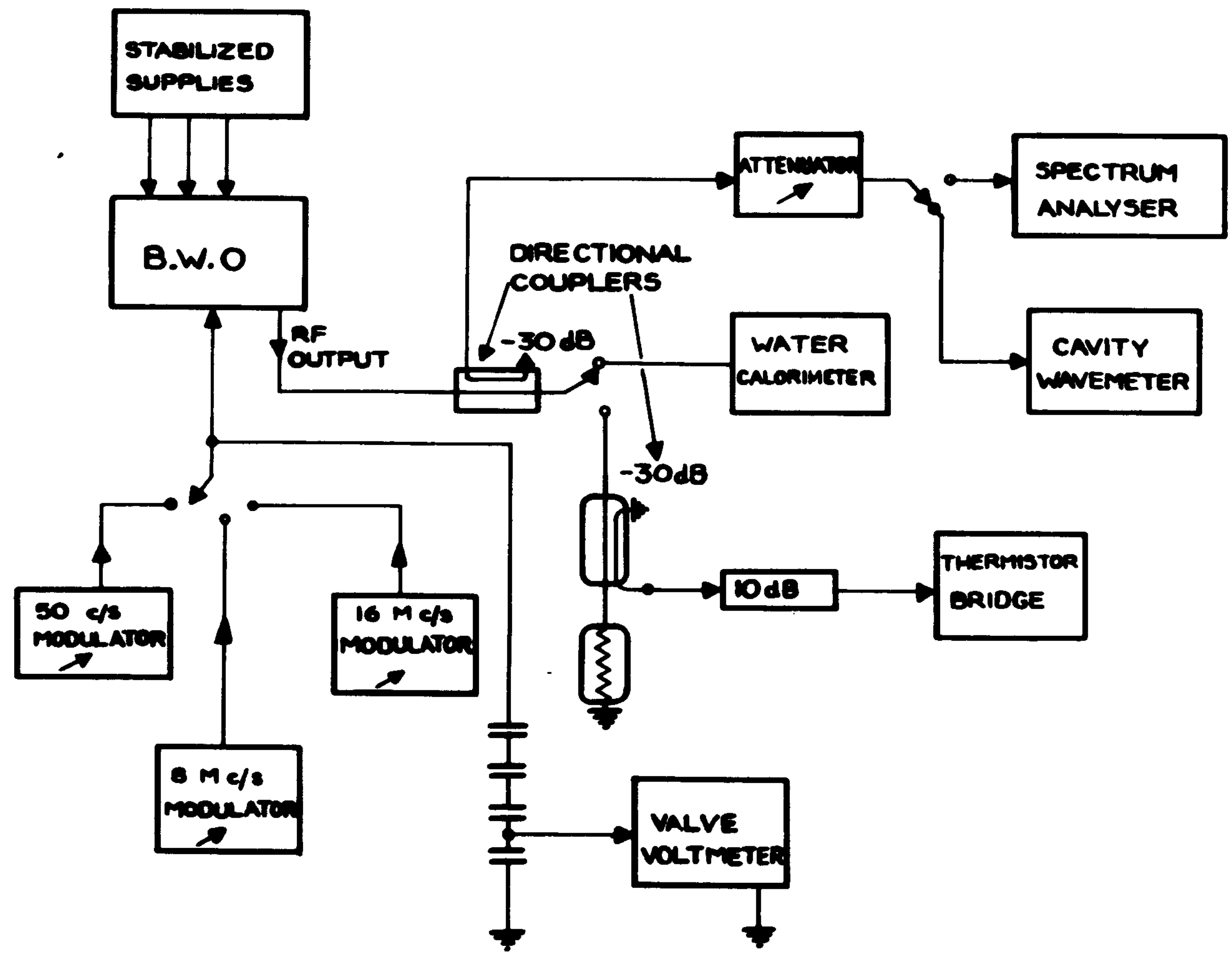


FIG. I BLOCK DIAGRAM OF EXPERIMENTAL EQUIPMENT

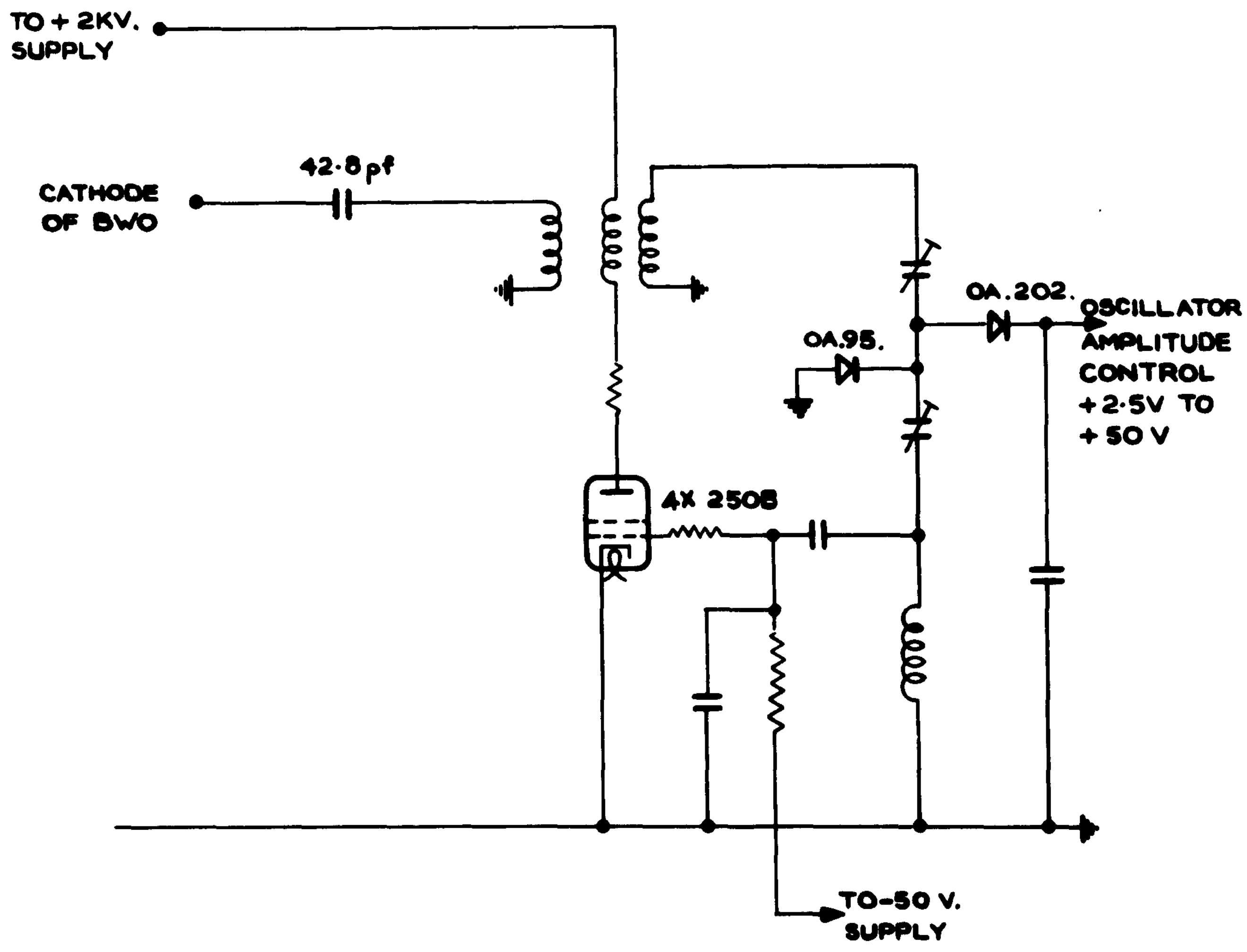
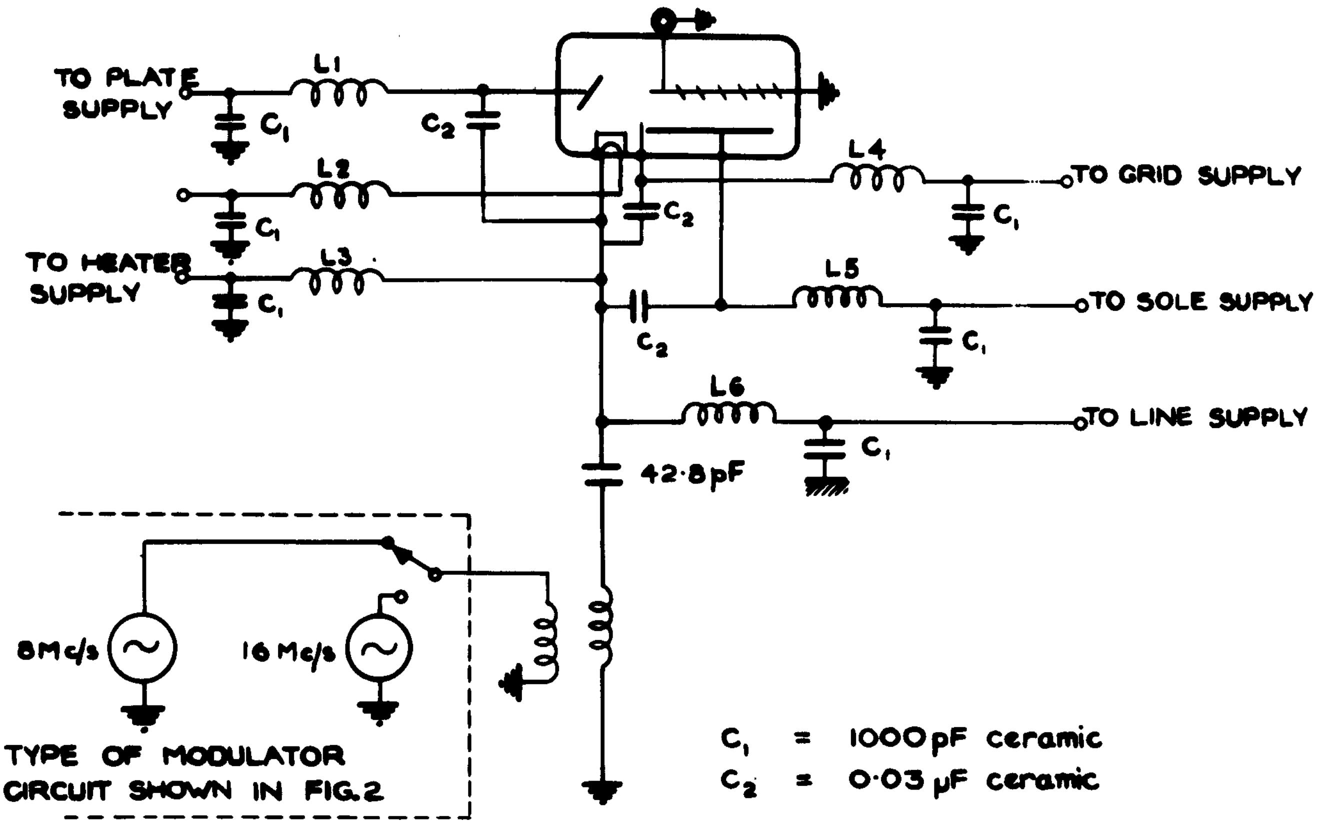


FIG. 2 CIRCUIT OF 16 Mc/s MODULATOR



C_1 = 1000pF ceramic
C_2 = 0·03 μF ceramic

L2 = } 43T. 16 SWG
L3 = } 2" DIA. FORMER

L1 = } 85T 36SWG
L4 = } ALADDIN FORMER
L5 = }

L6 = 50T 22 SWG En
2" DIA. FORMER

FIG. 3 DECOUPLING OF BWO AND POWER SUPPLIES

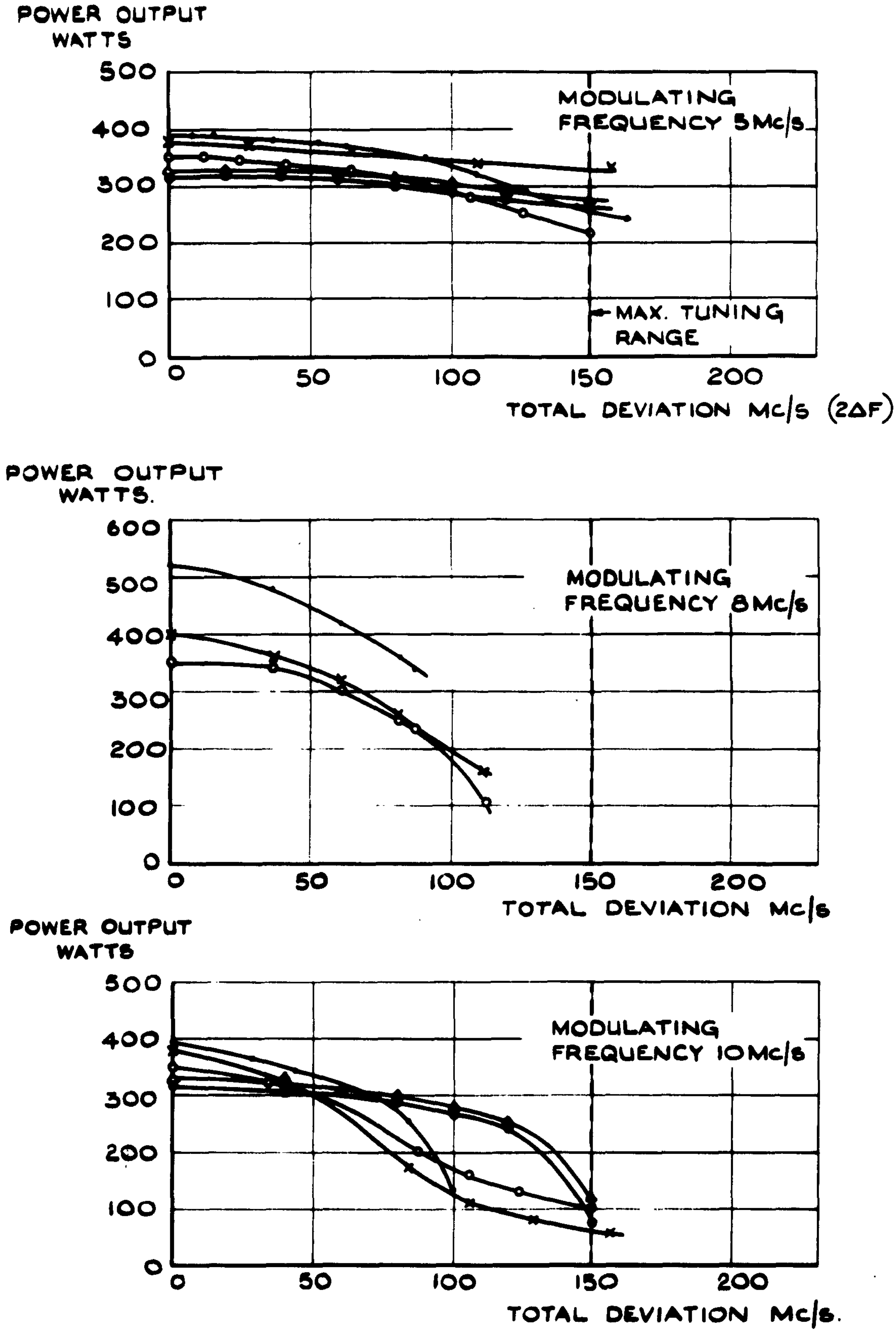


FIG.4 VX 9224/CV6102 (520-670 Mc/s)
VARIATION OF OUTPUT POWER WITH MODULATING FREQUENCY AND DEVIATION

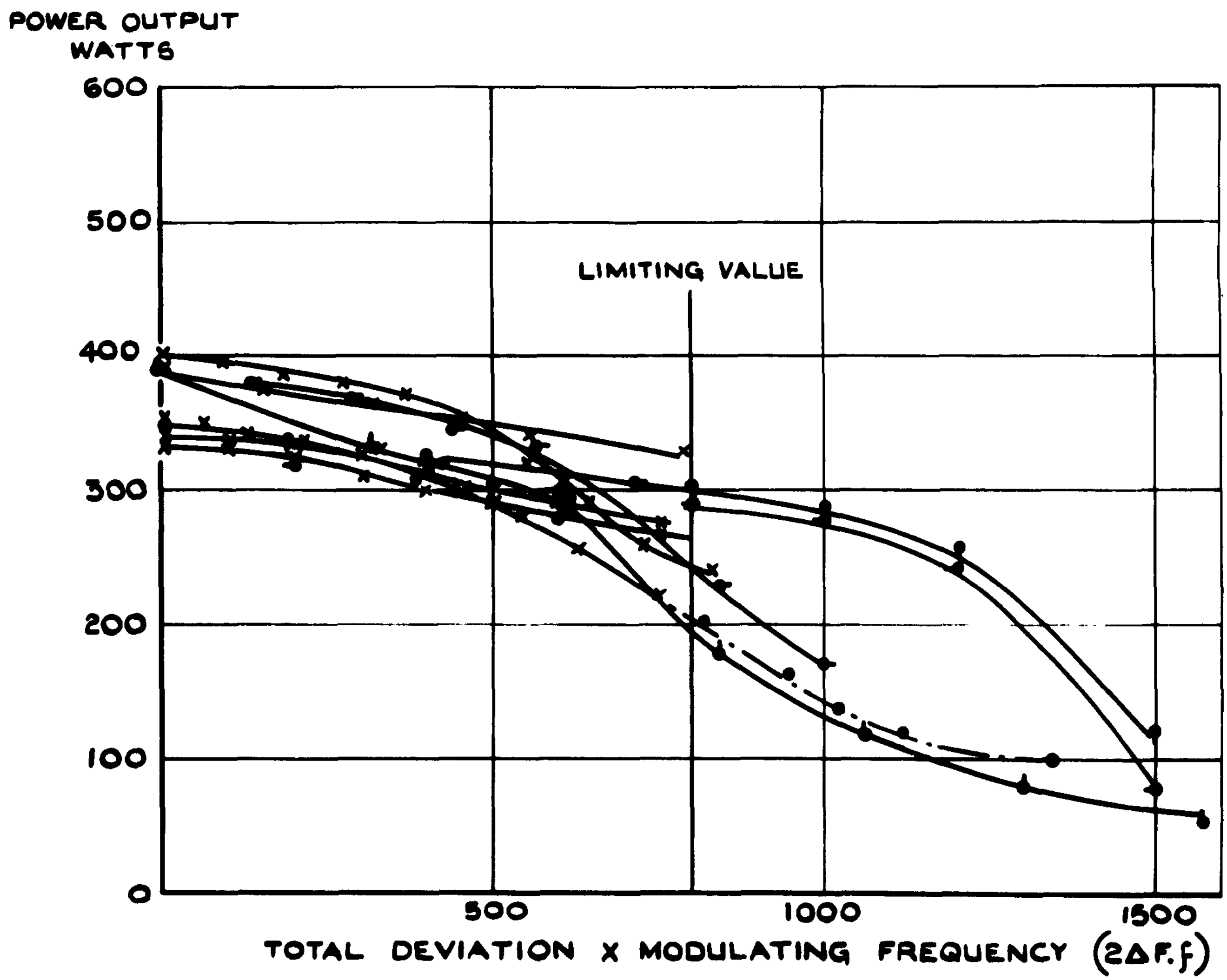


FIG.5 VX 9224/CV 6102 (520-670 Mc/s)
VARIATION OF OUTPUT POWER WITH (2ƒ.ΔF)
FOR ƒ OF 5, 8, 10 Mc/s

FREQUENCY

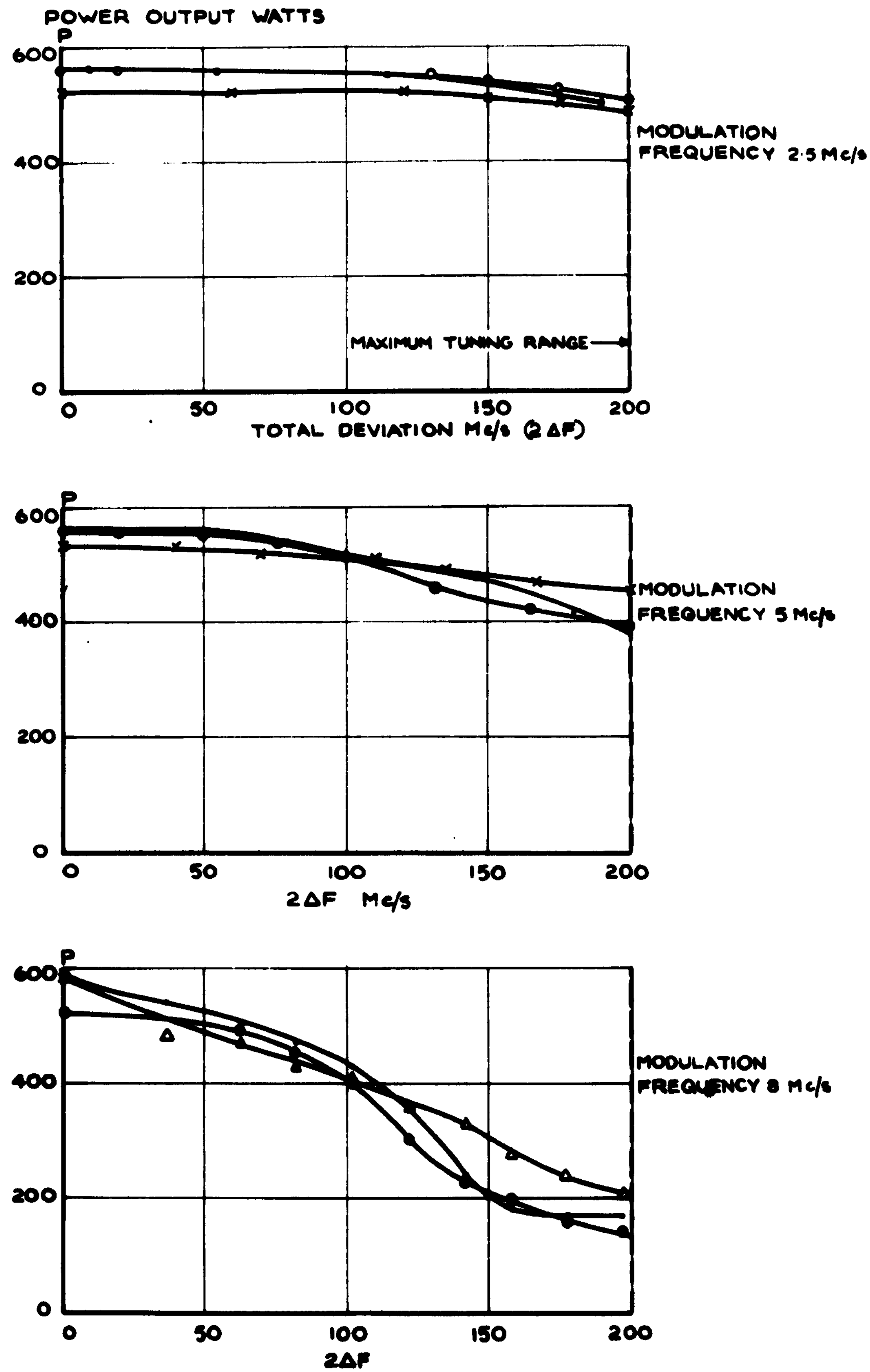
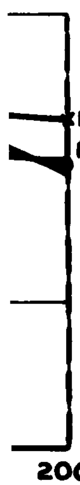
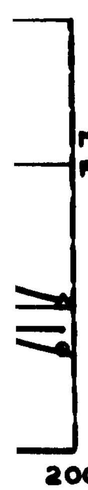


FIG 6 VX9239/CV6124 (6
VARIATION OF OUTPUT POWER WITH MODULATION

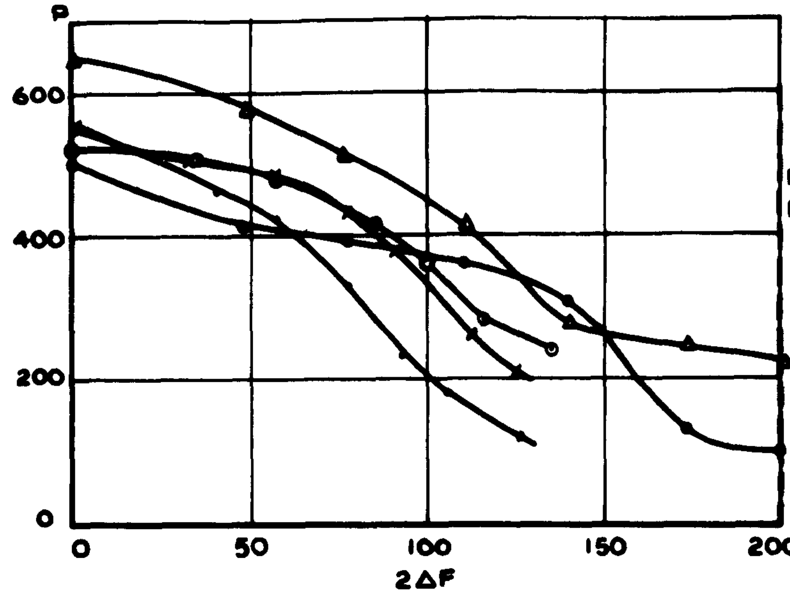
MODULATION
FREQUENCY 2·5 Mc/s



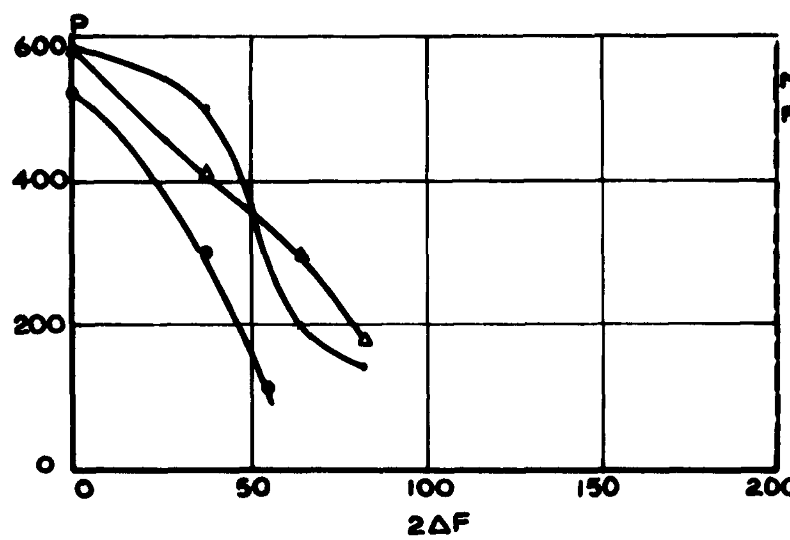
MODULATION
FREQUENCY 5 Mc/s



MODULATION
FREQUENCY 8 Mc/s



MODULATION
FREQUENCY 10 Mc/s



MODULATION
FREQUENCY 16 Mc/s

G 6 VX9239/CV6124 (660–860 Mc/s)
POWER WITH MODULATION FREQUENCY AND DEVIATION

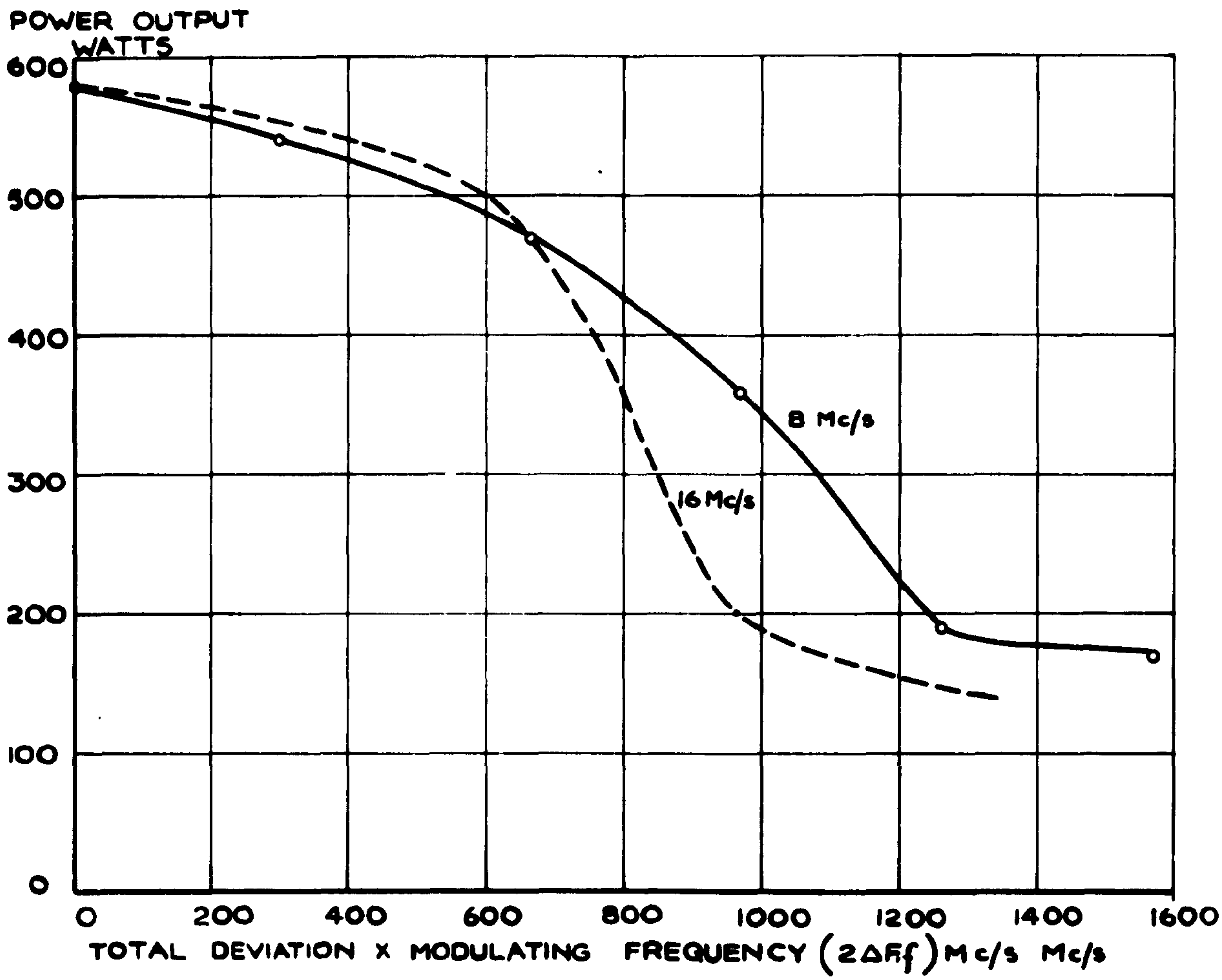


FIG. 7 VX9239/CV6124 (660–860 Mc/s)
VARIATION OF OUTPUT POWER WITH (2ΔF.f) FOR ONE VALVE

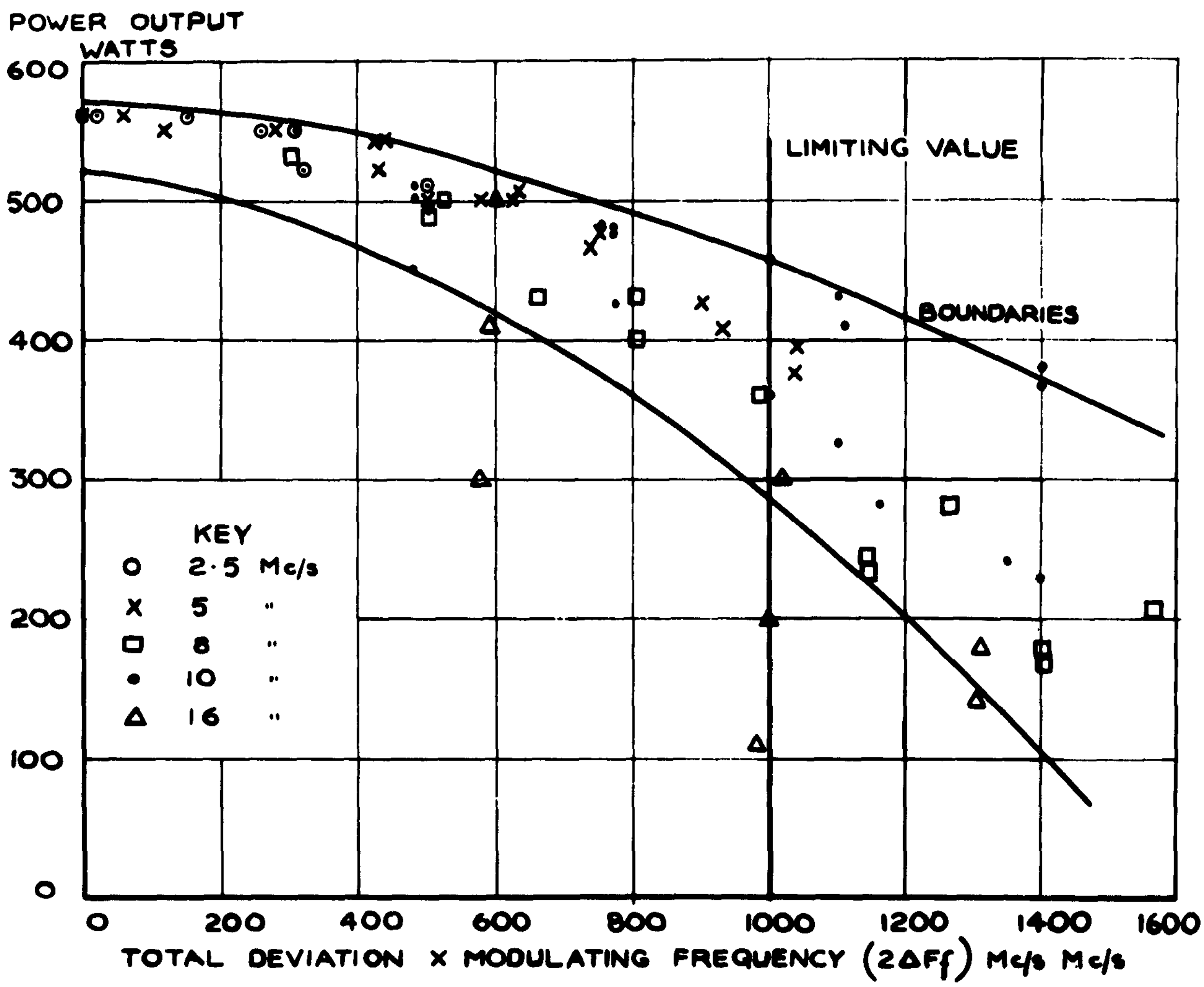


FIG. 8 VX9239/CV6124 (660–860 Mc/s)
VARIATION OF OUTPUT POWER WITH (2ΔFf) FOR A NUMBER OF VALVES

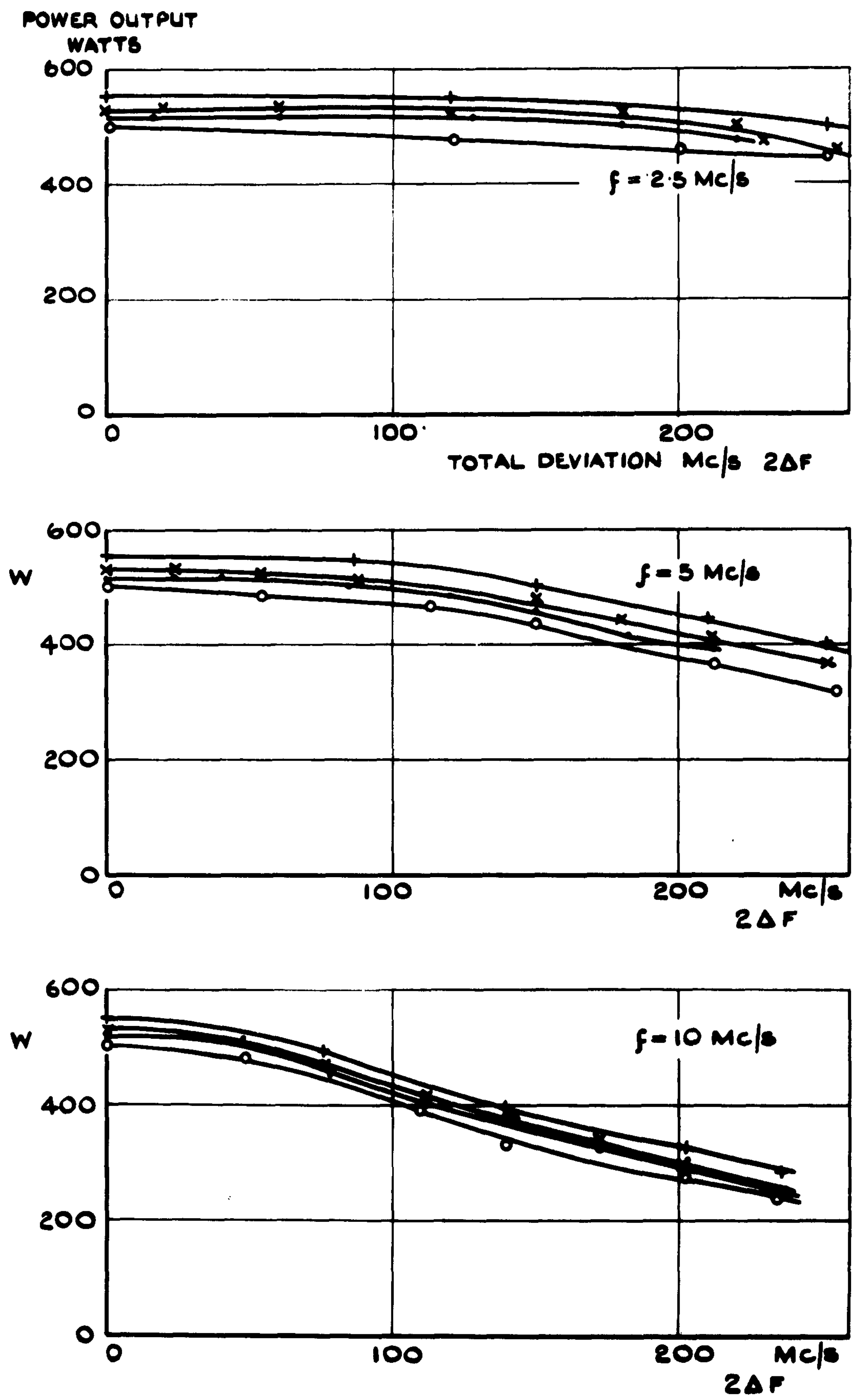
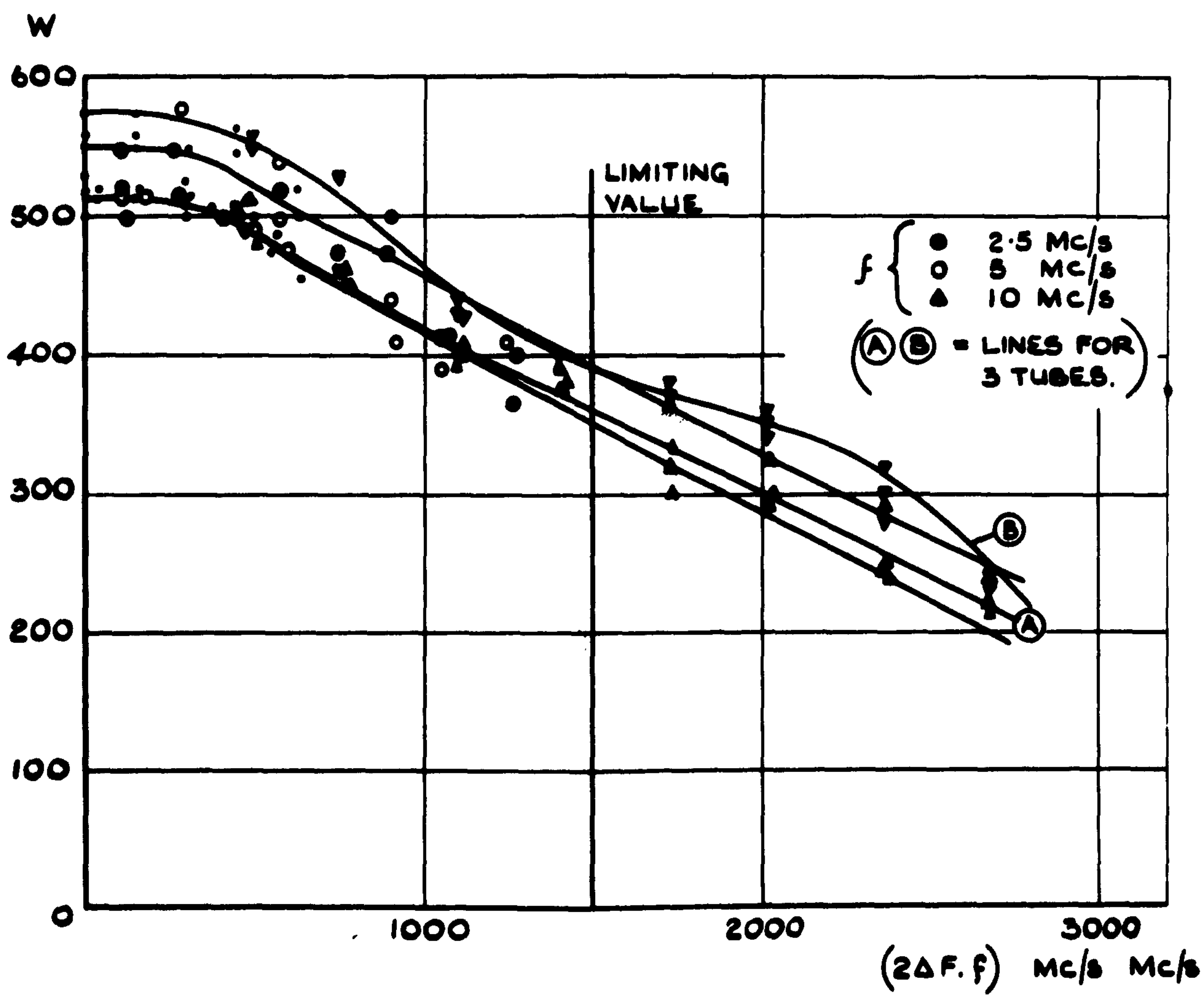


FIG.9 VX 9250 (850–1100 Mc/s)
VARIATION OF OUTPUT POWER WITH MODULATING FREQUENCY AND DEVIATION



; FREQUENCY

FIG.10 VX9250 (850-1100 Mc/s)
VARIATION OF OUTPUT POWER WITH (2ΔF. f)

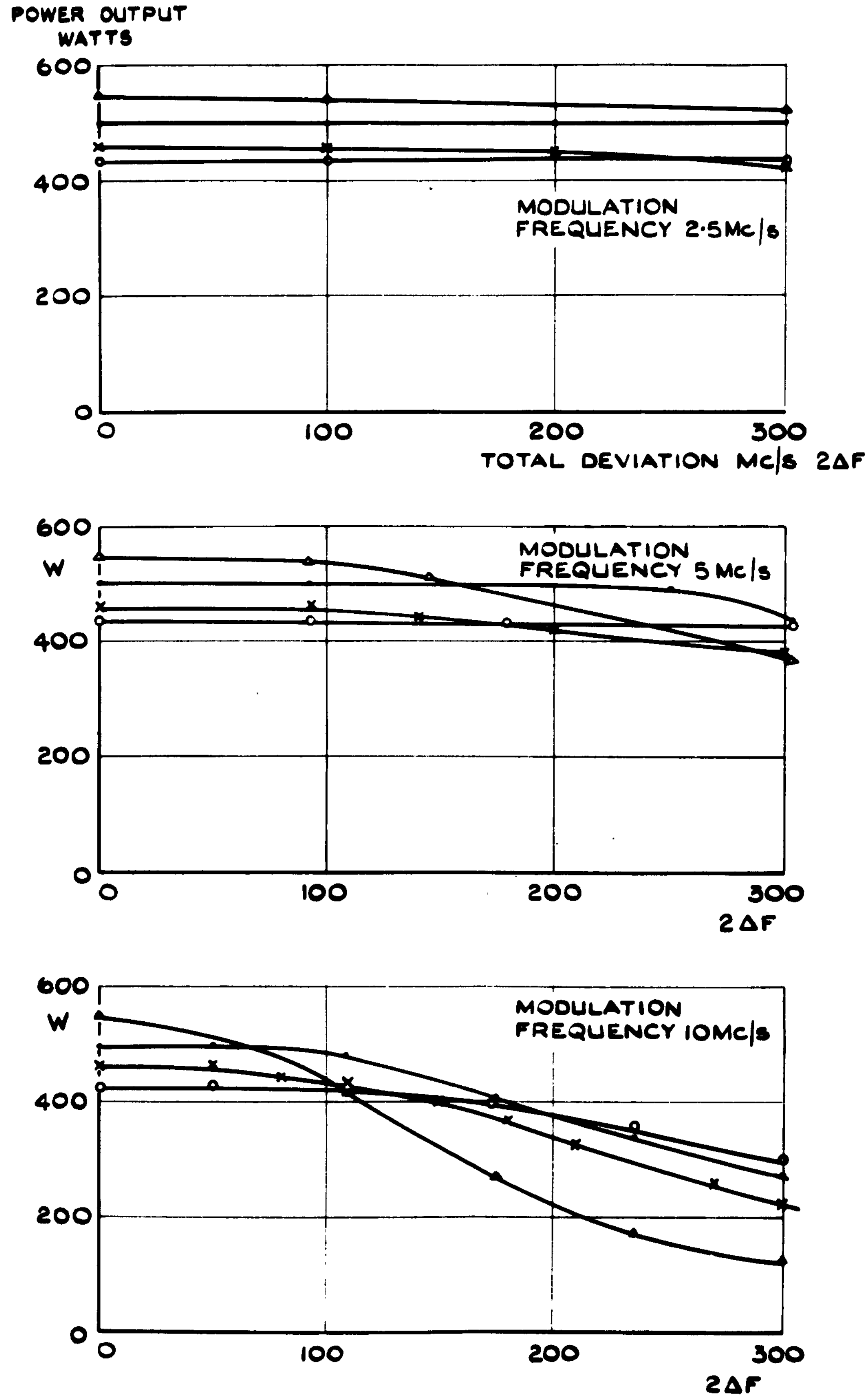


FIG.11 VX 9240 (1060-1370 Mc/s)
VARIATION OF OUTPUT POWER WITH MODULATING FREQUENCY AND DEVIATION

CONFIDENTIAL
RAD./P 6671

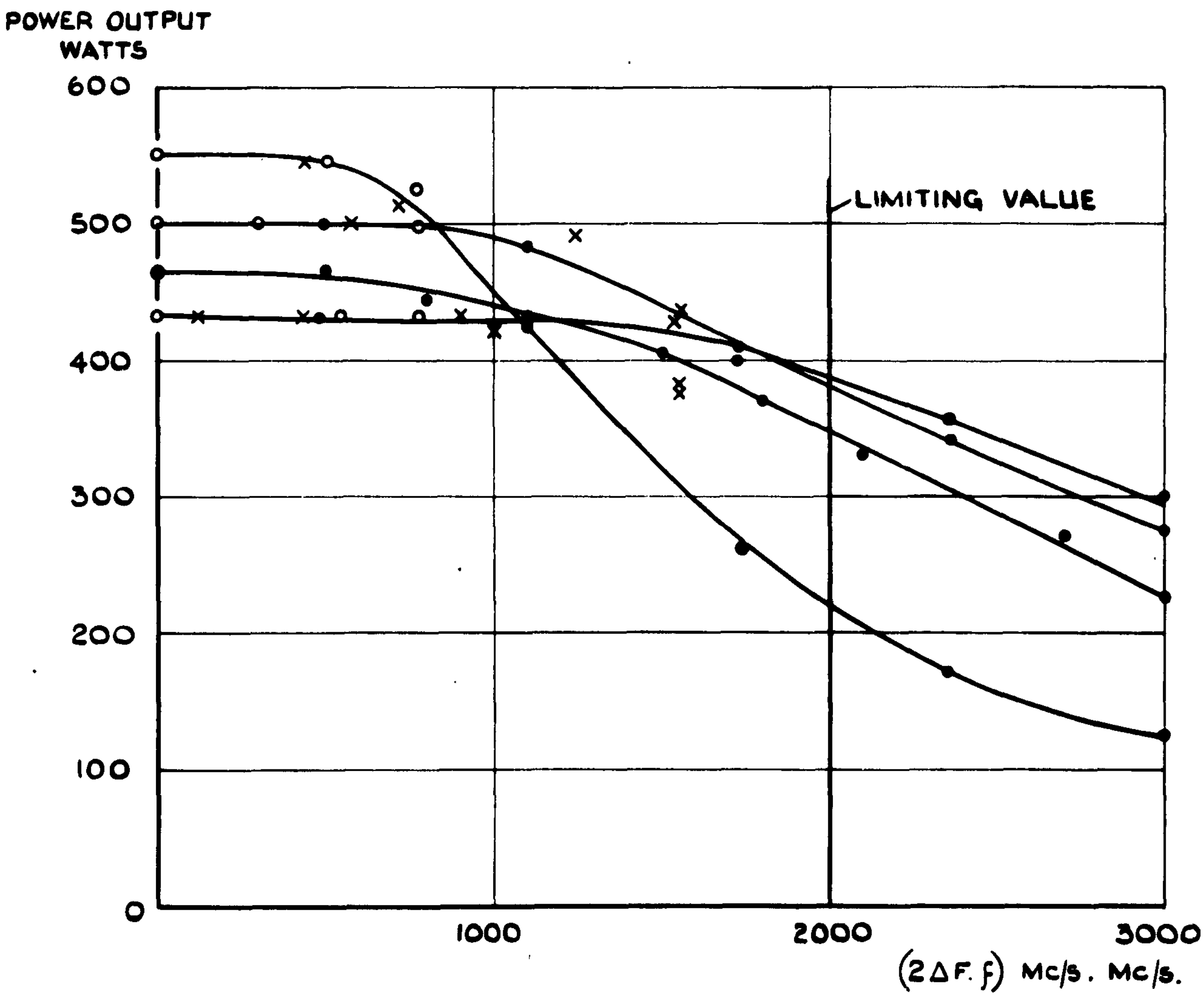


FIG.12 VX 9240 (1060-1370 Mc/s)
VARIATION OF OUTPUT POWER WITH (2ΔF. f)
FOR MODULATION FREQUENCY OF 2·5, 5, 10 Mc/s

FREQUENCY

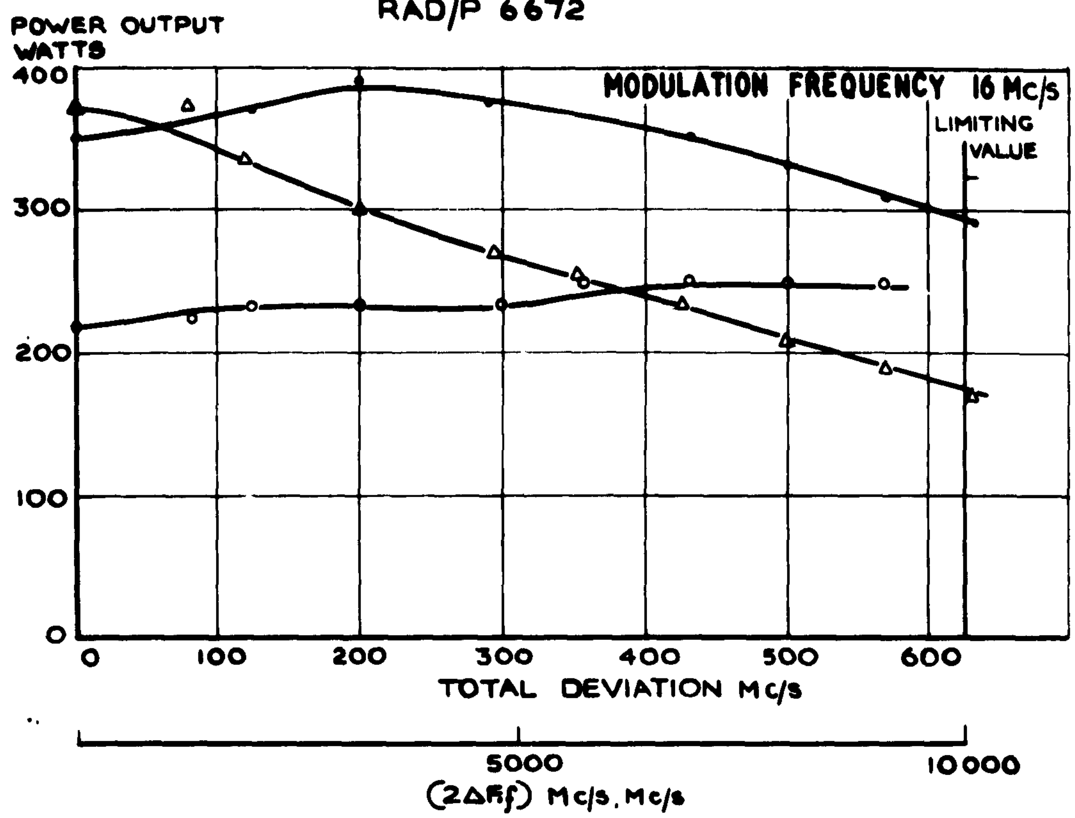


FIG. 13 VX 3510/CV2470 (2500–3100 Mc/s)
VARIATION OF OUTPUT POWER WITH DEVIATION AND (2ΔF.f)

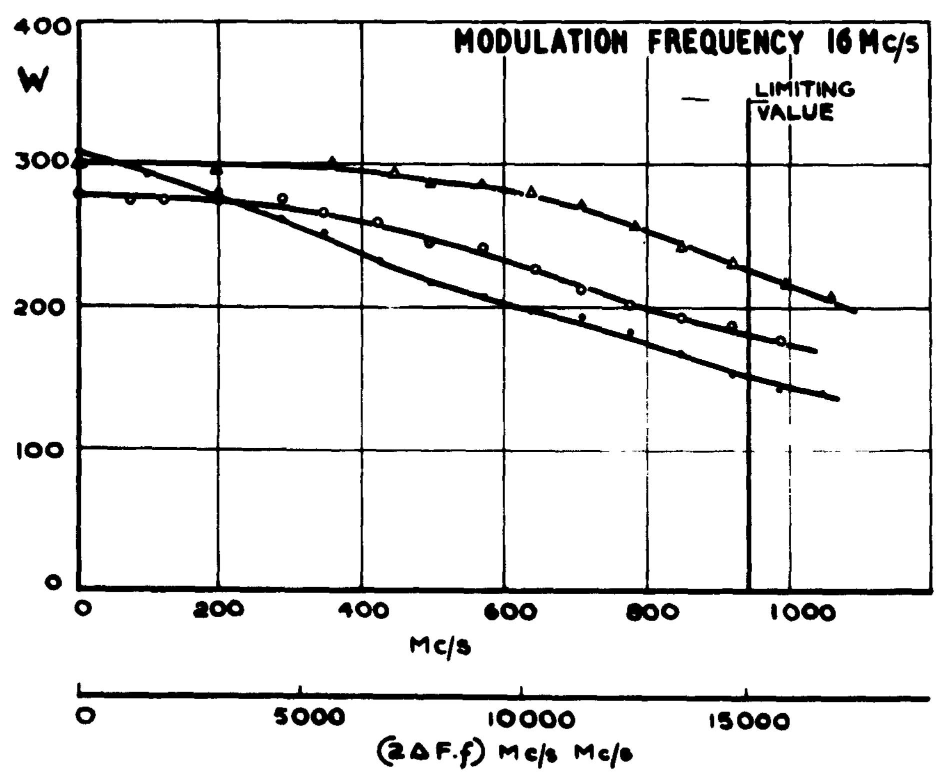


FIG. 14 VX 3512/CV 2471 (3000–4000 Mc/s)
VARIATION OF OUTPUT POWER WITH DEVIATION AND (2ΔF.f)

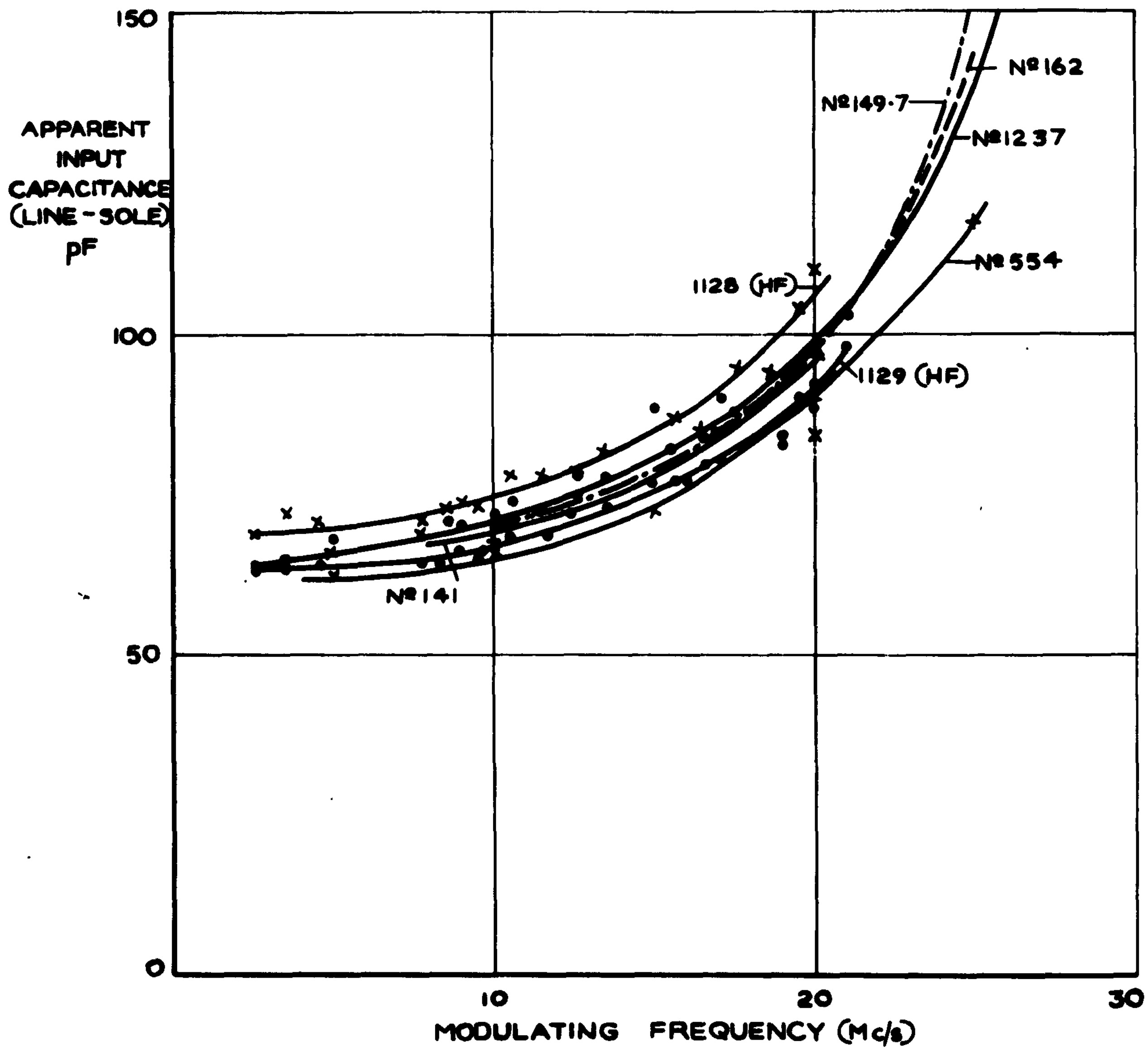


FIG. 15 VARIATION OF APPARENT LINE–SOLE CAPACITANCE WITH FREQUENCY FOR VX3510/CV2470

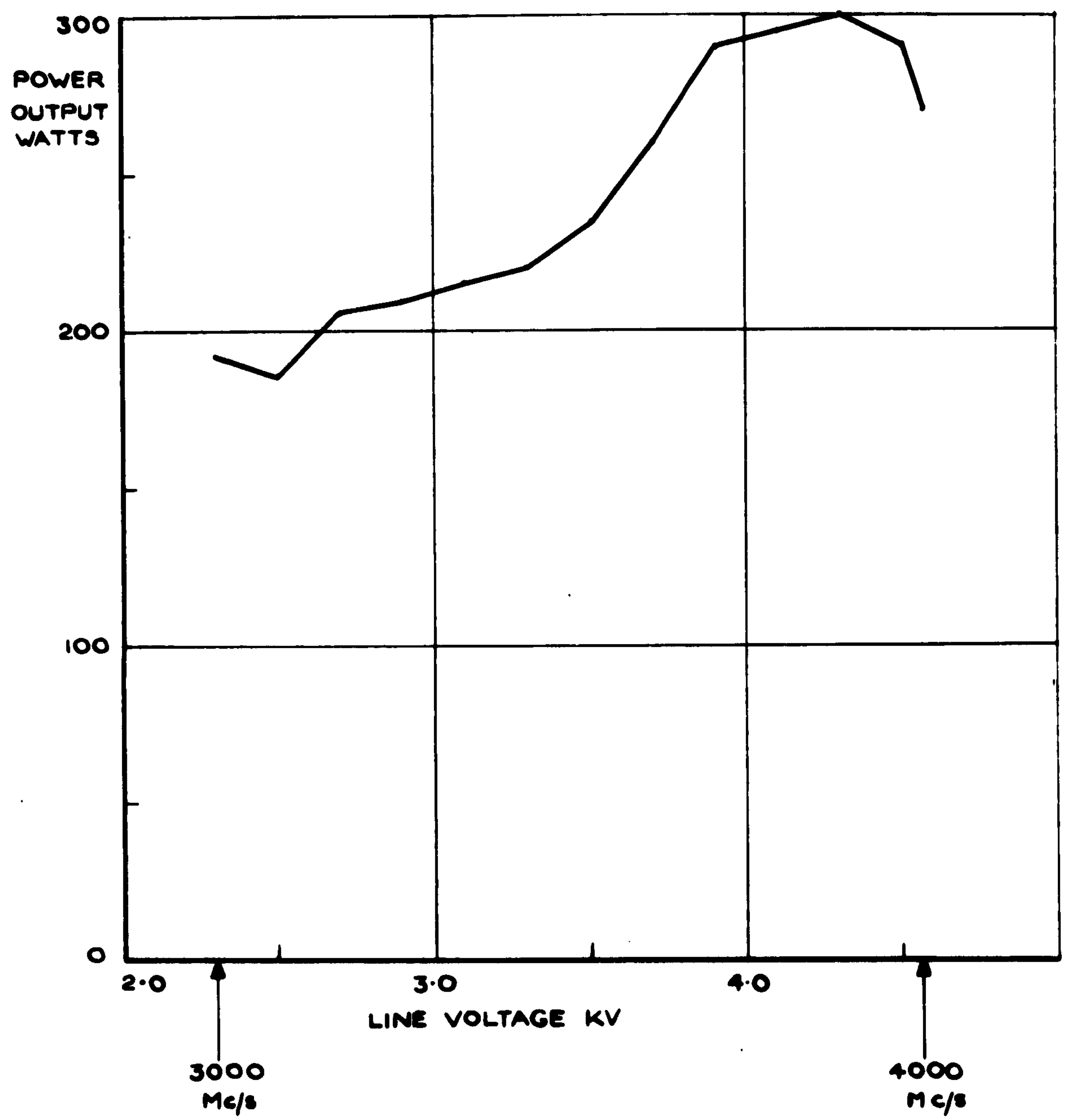


FIG. 16 (VX 3512)
TYPICAL POWER OUTPUT/FREQUENCY CURVE FOR BWO

DETACHABLE ABSTRACT CARDS

These abstract cards are inserted in Technical Reports for the convenience of librarians and others who need to maintain an Information Index.

Detached cards are subject to the same Security Regulations as the parent document, and a record of their location should be made on the inside of the back cover of the parent document.

CONFIDENTIAL

Sewards, A. — 621.385.633.24 :
Yeates, W.F.J. — 621.376.3

SIDE-EFFECTS OF FM BY HIGH FREQUENCIES ON M-TYPE BACKWARD WAVE OSCILLATOR VALVES

Royal Aircraft Establishment Technical Report 65081 — April 1965

The effect on six types of backward wave oscillator valve covering the frequency range from 520 to 1370 Mc/s and 2500 to 4000 Mc/s is described under conditions where they are frequency modulated at frequencies from 2.5 to 16 Mc/s over deviations extending to the full tuning range of the valve. The main effect common to all types is a reduction in RF power output, the greatest reduction occurring with high modulating frequencies and large deviations. It is concluded that if modulation over the tuning range

CONFIDENTIAL (Over)

CONFIDENTIAL

Sewards, A. — 621.385.633.24 :
Yeates, W.F.J. — 621.376.3

SIDE-EFFECTS OF FM BY HIGH FREQUENCIES ON M-TYPE BACKWARD WAVE OSCILLATOR VALVES

Royal Aircraft Establishment Technical Report 65081 — April 1965

The effect on six types of backward wave oscillator valve covering the frequency range from 520 to 1370 Mc/s and 2500 to 4000 Mc/s is described under conditions where they are frequency modulated at frequencies from 2.5 to 16 Mc/s over deviations extending to the full tuning range of the valve. The main effect common to all types is a reduction in RF power output, the greatest reduction occurring with high modulating frequencies and large deviations. It is concluded that if modulation over the tuning range

CONFIDENTIAL (Over)

CONFIDENTIAL

Sewards, A. — 621.385.633.24 :
Yeates, W.F.J. — 621.376.3

SIDE-EFFECTS OF FM BY HIGH FREQUENCIES ON M-TYPE BACKWARD WAVE OSCILLATOR VALVES

Royal Aircraft Establishment Technical Report 65081 — April 1965

The effect on six types of backward wave oscillator valve covering the frequency range from 520 to 1370 Mc/s and 2500 to 4000 Mc/s is described under conditions where they are frequency modulated at frequencies from 2.5 to 16 Mc/s over deviations extending to the full tuning range of the valve. The main effect common to all types is a reduction in RF power output, the greatest reduction occurring with high modulating frequencies and large deviations. It is concluded that if modulation over the tuning range

CONFIDENTIAL (Over)

CONFIDENTIAL

Sewards, A. — 621.385.633.24 :
Yeates, W.F.J. — 621.376.3

SIDE-EFFECTS OF FM BY HIGH FREQUENCIES ON M-TYPE BACKWARD WAVE OSCILLATOR VALVES

Royal Aircraft Establishment Technical Report 65081 — April 1965

The effect on six types of backward wave oscillator valve covering the frequency range from 520 to 1370 Mc/s and 2500 to 4000 Mc/s is described under conditions where they are frequency modulated at frequencies from 2.5 to 16 Mc/s over deviations extending to the full tuning range of the valve. The main effect common to all types is a reduction in RF power output, the greatest reduction occurring with high modulating frequencies and large deviations. It is concluded that if modulation over the tuning range

CONFIDENTIAL (Over)

CONFIDENTIAL

of the valve is necessary, the highest usable modulating frequency ranges from 8 Mc/s for the lowest frequency valve tested to 16 Mc/s for the highest.

CONFIDENTIAL

CONFIDENTIAL

of the valve is necessary, the highest usable modulating frequency ranges from 8 Mc/s for the lowest frequency valve tested to 16 Mc/s for the highest.

CONFIDENTIAL

CONFIDENTIAL

CONFIDENTIAL

of the valve is necessary, the highest usable modulating frequency ranges from 8 Mc/s for the lowest frequency valve tested to 16 Mc/s for the highest.

CONFIDENTIAL

CONFIDENTIAL

of the valve is necessary, the highest usable modulating frequency ranges from 8 Mc/s for the lowest frequency valve tested to 16 Mc/s for the highest.

CONFIDENTIAL

CONFIDENTIAL

[dstl]

Information Centre
Knowledge Services
[dstl] Porton Down
Salisbury
Wilts
SP4 0JQ
22060-6218
Tel: 01980-613753
Fax 01980-613970

Defense Technical Information Center (DTIC)
8725 John J. Kingman Road, Suit 0944
Fort Belvoir, VA 22060-6218
U.S.A.

AD#: AD396360

Date of Search: 26November 2008

Record Summary: AVIA 6/22442
Title: Side Effects of PM by High Frequencies on M-type Backward Wave Oscillator Valves
Availability Open Document, Open Description, Normal Closure before FOI Act: 30 years
Former reference (Department) Technical Reports 65081
Held by The National Archives, Kew

This document is now available at the National Archives, Kew, Surrey, United Kingdom.

DTIC has checked the National Archives Catalogue website (http://www.nationalarchives.gov.uk) and found the document is available and releasable to the public.

Access to UK public records is governed by statute, namely the Public Records Act, 1958, and the Public Records Act, 1967.
The document has been released under the 30 year rule.
(The vast majority of records selected for permanent preservation are made available to the public when they are 30 years old. This is commonly referred to as the 30 year rule and was established by the Public Records Act of 1967).

This document may be treated as UNLIMITED.